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Technology for the 21st Century

SLICE

A Revolutionary New Ship

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United States Japan Natural Resources/Marine Facilities Panel

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Introduction

SLICE is a new, patented ship technology that enables SWATH (small waterplane area twin hull) ships to operate at higher speeds while retaining their characteristic low motions in a seaway. SLICE technology's key innovation is reduction of wavemaking drag, which is accomplished by the introduction of four short struts, four teardrop-shaped submerged hulls, and speeds well beyond the 'hump' on the Froude resistance curve. Combining increased speed with stability in high seas, SLICE opens up new commercial and military markets to SWATH technology.

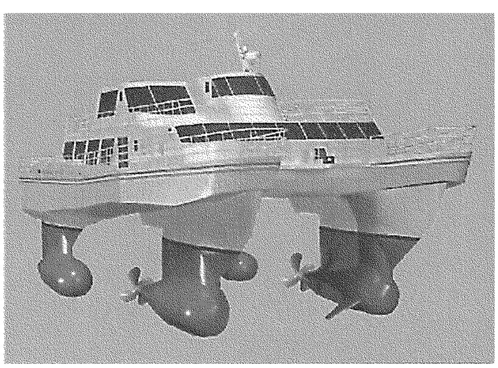

Figure 1: Model of SLICE ferry.

Throughout history, ship designers have sought a hullform for ocean-going vessels that combines excellent seakeeping in high sea states with high speed. For centuries, the prevailing design was the monohull.

In the early 1900s, with the successful integration of onboard power, high speed became achievable, and demand for ever-faster ships increased. As available installed power reached its limit, however, designers began investigating a new way to increase speed: reducing hull resistance. Several advanced hull forms resulted from these efforts. Displacement hull variants like catamarans, which utilize buoyancy, and hull forms incorporating dynamic lift such as planing hulls, hydrofoils, and surface effect ships, were designed and tested. Each of these innovations confirmed that design improvements could produce higher speeds.

Throughout this quest for speed, stability in high seas remained a critical issue. A high-speed vessel is useless in unprotected water unless it can survive the ocean's unforgiving environment. As a naval officer once observed, "Sea State is a war stopper." Thus, for generations, a vessel that combines high speeds and excellent stability has been the Holy Grail of ship designers. Four decades ago, Lockheed Martin joined this quest for the optimum hull.

The first technology that Lockheed Martin explored was that of the hydrofoil, building *Plainview,* the Navy's largest and fastest hydrofoil.

This work, conducted in the 1960s, led to Lockheed Martin's surface-effect efforts in the 1970s. Lockheed Martin designed the 2KSES solid wall surface-effect ship and

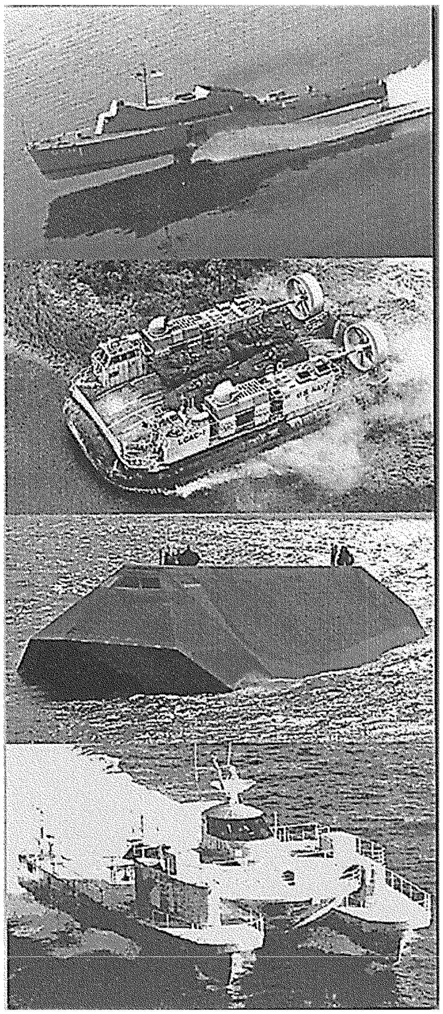

Figure 2: History of advanced ships at Lockheed Martin

built the landing craft air cushion (LCAC) flexible skirt air-cushion ships for the U.S. Navy. As technologies evolved, so did the ships. The next step was the stealthy ship *Sea Shadow*. Lockheed Martin and the U.S. Navy developed this vessel using SWATH technology--achieving low motions in high sea states and leaving a water 'trail' much less discernible than that of conventional ships.

Experience gained from these programs led to the development and patent of the revolutionary SLICE technology.

The Challenge

In high seas, most ships must sacrifice either speed or seakeeping ability, and neither can be achieved without size. To survive in high sea states and go fast, conventional displacement ships must be large. The relationship between a ship's maximum speed and its hull length is called 'hull speed.' For example, to reach a speed of 30 knots, a vessel must be at least 550 feet long. This limit on maximum speed--which applies to virtually all ship types, commercial and military--is shown in Figure 3. Consequently, small, conventional displacement ships are unable to do high-speed missions.

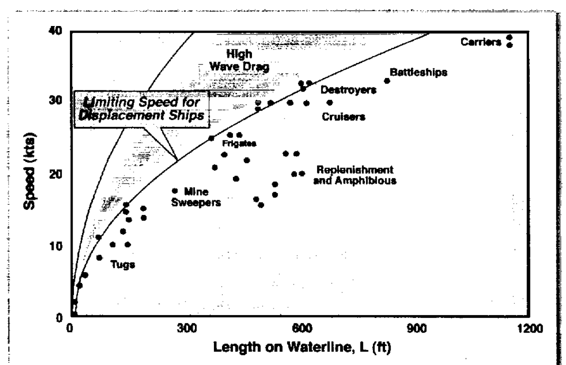

Figure 3: Limiting speed for displacement ships.

In addition to speed, a ship's size also limits its ability to perform in a seaway. Figure 4 shows the relationship of size to capability in a seaway for several generations of ship hull forms. For example, to be fully operational in a seaway of 15-foot-high waves, a vessel must be 500 feet long. This sea-state limitation further emphasizes the unsuitability of small, conventional displacement ships for high-speed missions, especially in high seas.

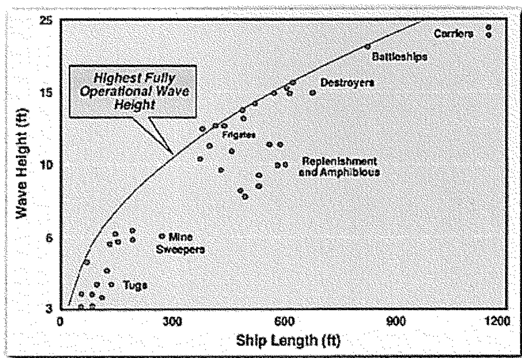

Figure 4: Limiting sea state for displacement.

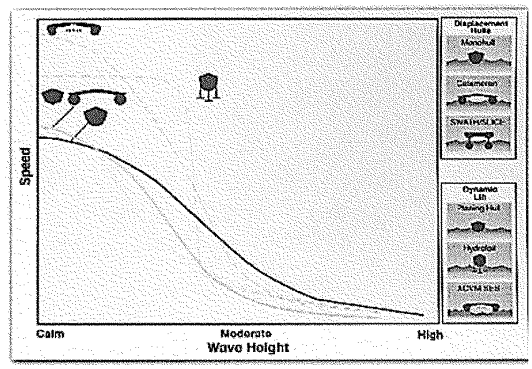

Figure 6: Wave height.

Some advanced hull forms use dynamic lift to achieve high speeds without adhering to conventional size restrictions. However, these craft, which include planing hulls, hydrofoils and hovercraft, are highly susceptible to the effects of high sea states.

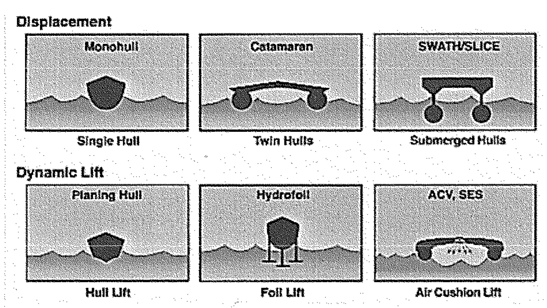

Figure 5: Advanced hullforms.

Though they may achieve high speeds in calm, inshore waters, the higher sea states found offshore require these ships to slow down for the safety of the vessel and its cargo as well as for the comfort of its passengers. As shown in Figure 6, a catamaran must slow down in high seas to avoid passenger and crew seasickness, severe structural slamming and a wet deck. In high seas, performance of hulls that depend on dynamic lift also suffers: planing hulls and hydrofoils are subject to loss of lift, and air cushion vehicles can experience venting.

Seakeeping thus limits these advanced, high-speed vessels from providing an overall effective platform for many open-water applications--including ferrying, search and rescue operations, and military missions.

The quest to improve seakeeping led to development of the SWATH hullform. Utilizing submerged submarine hulls, wave-piercing struts and an elevated platform, the SWATH hullform has a low waterplane area that is less affected by waves than its predecessors, as shown in Figure 7. The result is increased stability in high seas. SWATH hulls, however, are still restricted to lower speeds. This lack of speed limits the effectiveness of SWATH, and to date, ship designers and operators have confronted the dilemma of choosing either speed or stability.

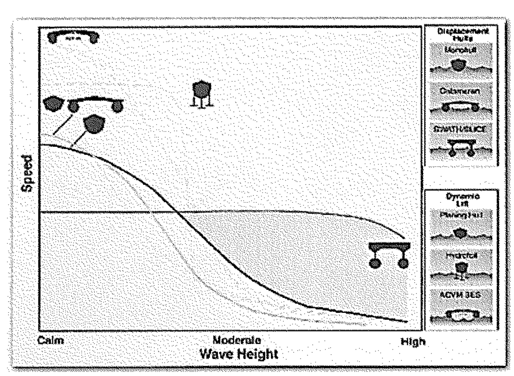

Figure 7: Sea state advantage of SWATH ship hullform.

Efforts to improve the seakeeping ability of the faster hullforms met with little success. Lockheed Martin, therefore, decided to attempt to increase the speed of the stable SWATH design. The SLICE hull form is the result.

The Physics of Resistance

Resistance of a ship comprises two principal components: (1) viscous resistance stemming from the friction of the water against the hull, and (2) wavemaking resistance leading to the formation of the waves following the ship, known as the Kelvin wake. At high speeds, wave-generating resistance composes 50% to 60% of total resistance. This produces the distinct Kelvin-wake pattern behind the vessel.

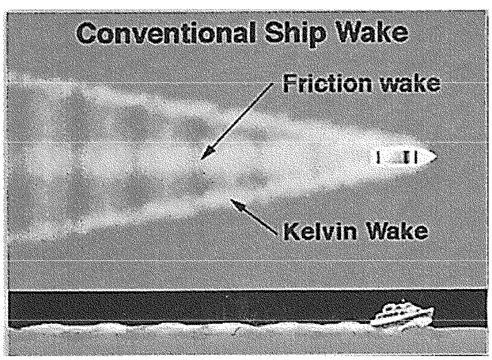

Figure 8: Conventional ship's wake.

The transverse wave component of the Kelvin-wake, observable as the large periodic waves within the V-pattern, is the larger part of the total wave drag. Until the 1970s, designers could do nothing to counteract the effect of wave drag on resistance and total performance.

The hull parameter governing wave resistance is known as the Froude number. The Froude number relates the speed of a vessel to its length by the formula $F=V/\sqrt{g*L}$, where V is the vessel's speed, L the vessel's length and g the acceleration due to gravity.

Figure 9 shows that at low Froude numbers (low speed-to-length ratios), the wave resistance is low and the viscous resistance dominates. As speed (Froude number, or F) increases, wave resistance becomes a higher percentage of total resistance--until at the critical or 'hump speed,' wave resistance exceeds viscous resistance. This large increase occurs when F = 0.4, and is maximum at F = 0.5. Conventional ships always operate at Froude numbers below this primary hump speed (see Figure 9). To achieve high speed, naval architects design their ships to operate below the F = 0.4 threshold by incorporating long lengths. Only Navy ships with high installed-propulsion power can operate at a Froude number above 0.4.

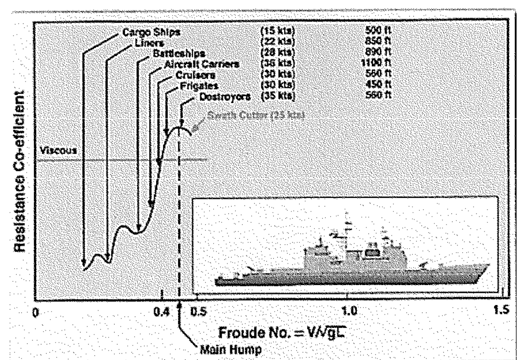

Figure 9: Resistance co-efficient.

The first attempt by naval architects at reducing wave resistance was the bulbous bow, which is widely used on cruise ships, ocean tankers and cargo vessels. This design cancels a segment of the wave created, thereby reducing the energy in the Kelvin wake. The bulbous bow lowers the height and increases the period of the transverse wave created by the ship. While the bulbous bow reduces the energy of the Kelvin wake by about 10%, this reduction occurs only at the design speed of the ship. Therefore, this design improves the efficiency of transit at cruise speed but provides little improvement at other speeds.

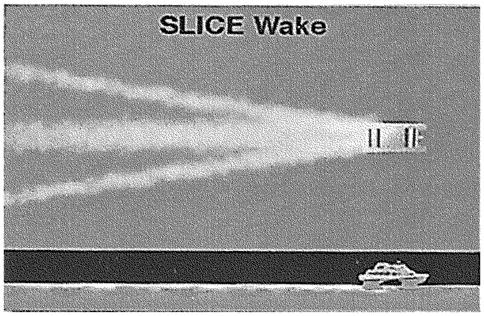

Figure 10: SLICE's wake.

The SWATH ship *Sea Shadow* is an extension of this cancellation idea. This ship's lower hulls have a bulbous, 'Coke-bottle' shape, with thin struts that connect the lower hulls to the superstructure. This shape counteracts wave resistance, reducing the energy of the Kelvin wake by about 20%. The *Sea Shadow's* sculptured lower hull doubles the limited cancellation effect of the bulbous bow. But again, this effect is realized only at the optimum design speed.

Theory shows that at high Froude numbers, the transverse portion of the Kelvin wave is virtually eliminated, reducing the wave resistance to low Froude number values.

This leads to the idea that to significantly reduce wave resistance, a ship should operate at large Froude numbers, thereby surpassing the limiting hump. The idea is analogous to a supersonic jet overcoming wind resistance by surpassing the sound barrier. SLICE is designed around this high-Froude-number principle.

The Technology of SLICE

One way to increase the Froude number for a hull is to rearrange displacement hulls into segments that have short lengths. SLICE employs such an arrangement.

When comparing vessels of equal displacement, a SLICE vessel's hulls are one quarter the length of SWATH hulls. The correspondingly larger diameter of SLICE hulls provides the required displacement. For the same operational speed, this innovation doubles the Froude number. For example, a 500-ton SWATH operating at 25 knots would be near its wave resistance hump, while a SLICE of equal displacement would be operating well beyond its hump--taking advantage of substantially reduced wave resistance.

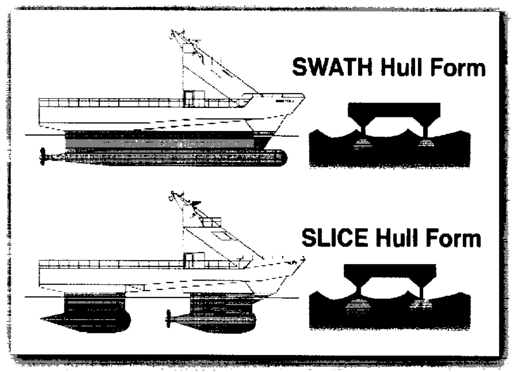

Figure 11: Comparison of SWATH & SLICE hullforms.

A comparison of the resistance for these two vessels is shown in Figure 13 (SWATH) and 14 (SLICE). The hump in the resistance still occurs at F = 0.5 (see Figure 12); however, due to the short lower hulls, this phenomenon occurs at low speeds, and SLICE's engine is able to power over the created hump and achieve the high design speed. By operating at high Froude numbers, SLICE's wave resistance is greatly reduced and SLICE outruns its own transverse wave pattern.

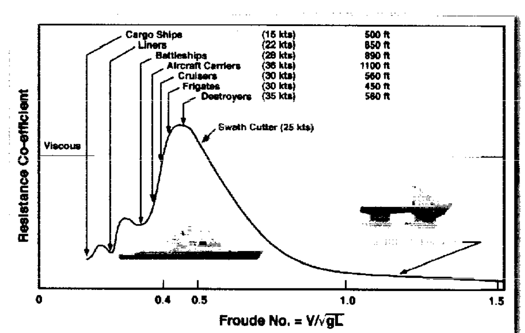

Figure 12: Comparison of viscous and wave making resistance for SLICE vessels.

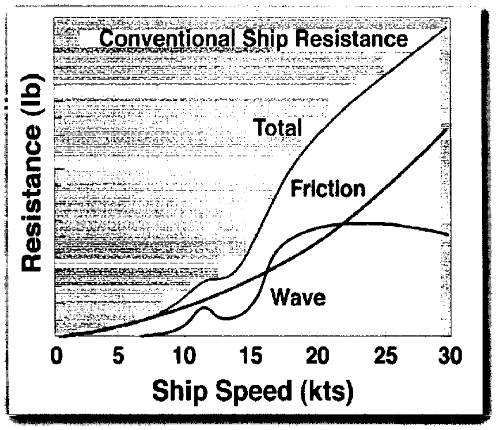

Figure 13: Conventional ship resistance.

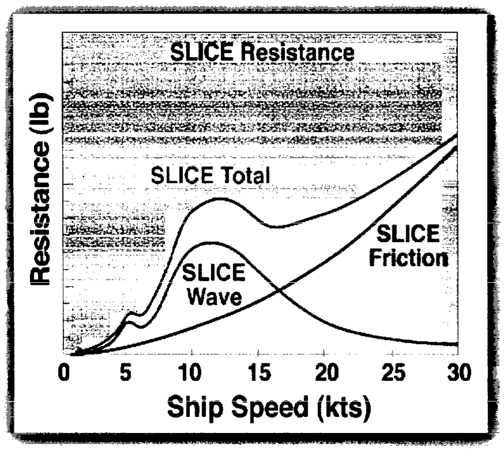

Figure 14: SLICE ship's resistance.

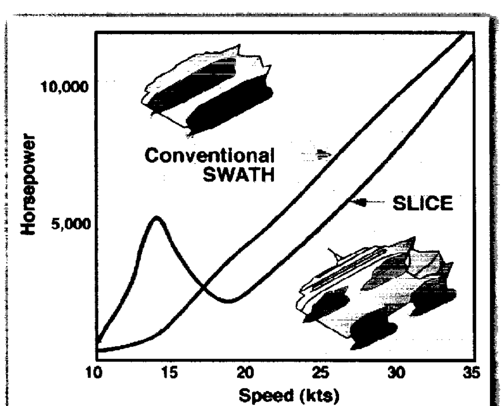

Figure 15: SWATH vs. SLICE propulsion power.

As shown in Figure 15, the SLICE advantage can reduce propulsion power, required to achieve the same speed, by 20% to 35% or for the same power, increase the speed by 3 knots.

The improvements in SLICE's resistance characteristics translate into several quantified benefits. Since SLICE is based on the principles of SWATH technology, SLICE possesses all of a SWATH's advantages: smaller size, better seakeeping and cheaper acquisition and operating costs. Adding to these benefits, SLICE has higher speed, reduced wake, better range, endurance and fuel consumption, and is built utilizing conventional shipyard practices, including design, construction, materials and equipment. Additional benefits are modular payload capability, simplified payload balancing (due to forward weight), large open deck space, unobstructed stern for loading and unloading, and propulsion amidships--which substantially reduced the chances of fouling and propeller damage. These factors combine to create an optimum small, affordable ship that operates at high speed in high seas.

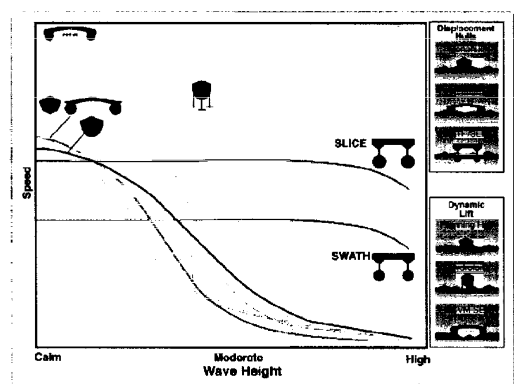

Figure 16: SLICE speed/sea state capability compared to advanced hullforms.

Advanced Technology Demonstration

SLICE is more than just theory. Lockheed Martin has designed an Advanced Technology Demonstration (ATD) vessel, built by Nichols

Brothers Boat Builders, Inc. and Pacific Marine & Supply Company, Ltd. A cooperative agreement with the Office of Naval Research (ONR) to validate the SLICE technology provided the impetus for this effort. The SLICE ship has completed all sea tests and has met or exceeded all performance goals, including very low ship motions while achieving 30 knots in wave heights 12 feet.

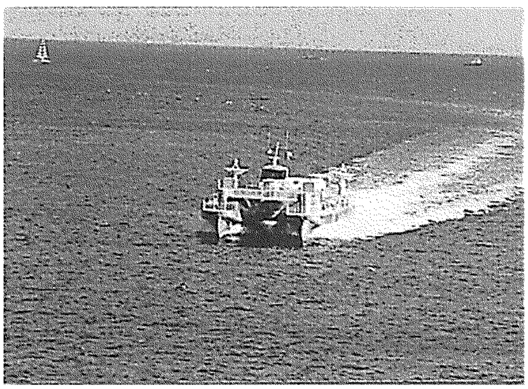

Figure 17: SLICE ship's low wake at 30 knots.

The ONR is impressed with the results and has approved further research involving SLICE. In addition to the U.S. Navy, other government agencies that have witnessed the superior performance of SLICE include the U.S. Coast Guard, U.S. Marines and U.S. Naval Reserves. Specifically, the Coast Guard is examining the application of SLICE technology to their next-generation cutters while both the Marines and the Naval Reserves are interested in applying SLICE to littoral warfare.

The Future of SLICE

Future plans for the SLICE ATD ship include installation of a modular payload for commercial operations. A primary application is a fast, all-weather ferry operating among the historically difficult to navigate Hawaiian Islands.

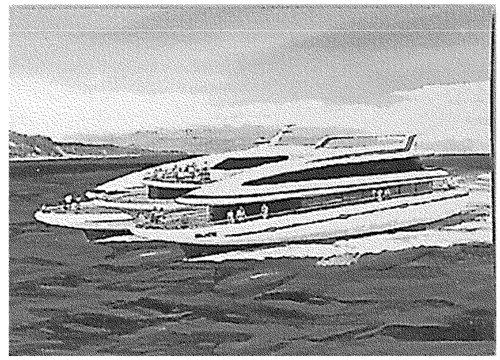

Figure 18: High-speed ferry.

Ship operators want small, affordable ships that operate at high speed in high seas. SLICE fulfills all these requirements and therefore is ideal for many government, military and commercial applications.

Possible government applications include patrol/interdiction, search and rescue, buoy tending, oceanographic and hydrographic

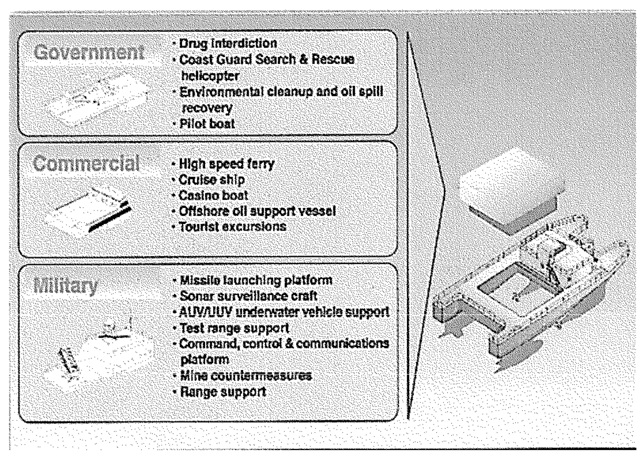

Figure 19: Mission candidates for SLICE hullform technology.

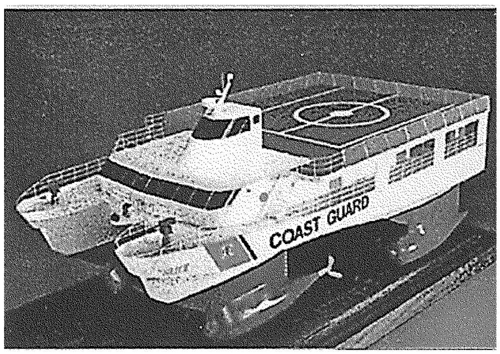

Figure 20: U.S. Coast Guard model.

Figure 21: SLICE recreational ship.

surveys, and missile/satellite tracking. These missions need great stability to carry out their primary operations but also benefit from speed in reaching their destinations. SLICE provides both of these capabilities as well as the benefits of simplified payload balancing, modular payload capability, an unobstructed stern and large exposed deck space.

Ideal commercial applications include offshore support, oil spill response, excursion vessels and recreation craft. Again, these vessels need stability for both operation and passenger/crew comfort, but require high speeds capable of getting them to their destinations quickly. For example, for offshore and oil spill response vessels, speed is crucial during emergencies. Again, the additional benefits of simplified payload balancing, modular payload, unobstructed stern and additional exposed deck space contributes to the overall appeal of SLICE.

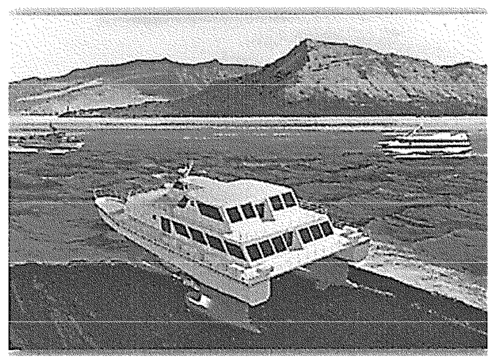

Figure 23: SLICE patrol boat.

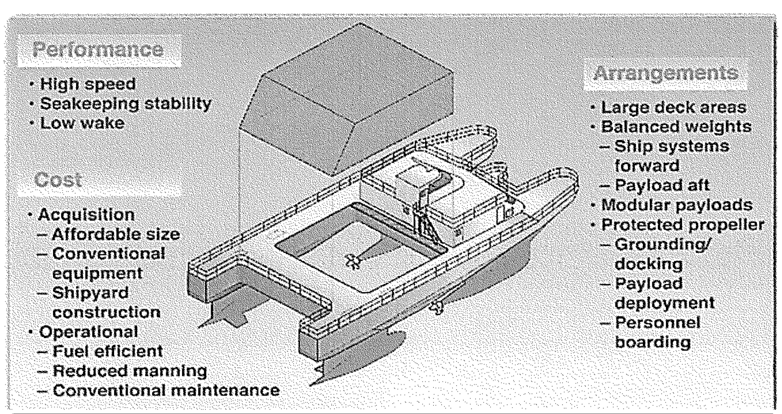

Figure 22: Schematic of modular payload.

Military coastal applications for SLICE include command, communications and control, missile launching, mine warfare, surveillance, helicopter support, special operations warfare, autonomous underwater vehicle/underwater unmanned vehicle (AUV/UUV) support, and test/range support. A high-speed, fully operational vessel could have an immense positive impact on military operations. Quick response, unlimited operations in high seas and low cost make SLICE an ideal addition to the U.S. Navy's arsenal.

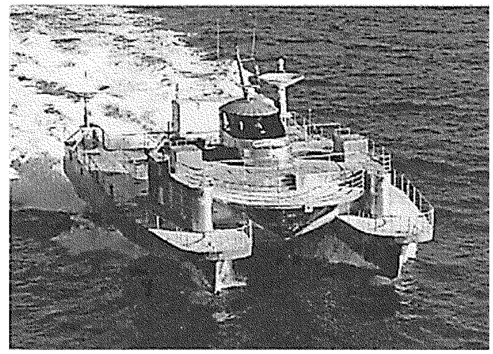

Figure 24: SLICE advanced technology demonstrator.

Conclusions

The low-motion capability of SWATH vessels makes them ideal candidates for a variety of missions; however, lack of sufficient speed has prevented SWATH from making a large impact on the industry.

SLICE is a technological breakthrough that allows SWATH vessels to obtain high speed without sacrificing efficiency. The inherently small size and modularity of SLICE vessels identifies them as ideal candidates for meeting the high-speed and low-motion requirement of commercial, government and military markets.

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Terry Schmidt is a Manager at Lockheed Martin Naval Electronics & Surveillance Systems Company in Sunnyvale, California.

Since joining Lockheed Martin in 1973, Mr. Schmidt has specialized in the design and development of advanced, high-performance ships. In 1985, he received Lockheed Martin's prestigious Robert E. Gross Award for Engineer/Scientist of the Year.

Mr. Schmidt holds four patents covering SWATH and SLICE ship technologies, including the stealth ship *Sea Shadow*, the Navy's TAGOS-19 and -23 class ships, and most recently the SLICE Advanced Technology Demonstrator. Mr. Schmidt is also Lockheed Martin's Program Manager for the Navy's SWATH AGOR 26 design and construction program.

Mr. Schmidt received his BS in aeronautical engineering from California State Polytechnic College, San Luis Obispo, in 1966 and MS in mechanical engineering from California State University, San Jose, in 1971.